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**ELECTRONIC DEVICE WORKPIECES, METHODS
OF SEMICONDUCTOR PROCESSING AND
METHODS OF SENSING TEMPERATURE OF AN
ELECTRONIC DEVICE WORKPIECE**

* * * * *

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1 ELECTRONIC DEVICE WORKPIECES, METHODS OF
2 SEMICONDUCTOR PROCESSING AND METHODS OF SENSING
3 TEMPERATURE OF AN ELECTRONIC DEVICE WORKPIECE

4 TECHNICAL FIELD

5 The present invention relates to electronic device workpieces,
6 methods of semiconductor processing and methods of sensing temperature
7 of an electronic device workpiece.

8 BACKGROUND OF THE INVENTION

9 It is preferred in the semiconductor and related arts to utilize
10 large wafers for fabrication of integrated circuits and other devices.
11 Large wafers are preferred inasmuch as an increased number of chips
12 can be fabricated from larger workpieces. As the size of the wafers
13 continues to increase as processing techniques are improved, additional
14 processing obstacles are presented.

15 For example, it is typically preferred to provide a substantially
16 constant temperature across the surface of the wafers being processed
17 because changes in temperature can influence device fabrication. Wafers
18 of increased diameters and surface areas experience increased
19 temperature fluctuations at various locations on the workpiece. In
20 particular, a partial vacuum is typically used to pull small diameter
21 wafers into direct thermal contact with a hot plate. Such processing
22 methods facilitate substrate temperature control because the substrate
23 temperature is closely associated to the temperature of the hot plate.
24

1 Fabrication of small sub-micron devices upon larger diameter
2 semiconductor wafers or workpieces requires minimal backside
3 contamination. As such, contact of the workpiece with a hot plate is
4 not typically not possible. Such workpieces are processed in
5 conventional operations upon spacers or pins that position the workpiece
6 approximately 0.1 millimeters above the hot plate heating surface. Such
7 spacing intermediate a chuck or hot plate and the workpiece results in
8 substrate temperatures which can be influenced by the environment
9 above the substrate. Inconsistencies in temperature across the surface
10 of the workpiece often result.

11 Absolute temperature and temperature uniformity of a workpiece
12 are parameters which are closely monitored during wafer and workpiece
13 fabrication to provide critical dimension (CD) control. Chemically
14 amplified resists are utilized in deep ultraviolet (DUV) lithography in
15 small micron geometries (eg., 0.25 microns and below). Chemically
16 amplified resists are particularly temperature dependent further increasing
17 the importance of temperature control and monitoring. Some thermal
18 resist processing steps require process windows ranging from 1-2 degrees
19 centigrade down to a few tenths of a degree centigrade. Meteorology
20 that is four to ten times more precise than conventional process
21 equipment may be required to provide thermal performance
22 measurements to 0.1 degrees centigrade.

23 One approach has disclosed the use of temperature sensors across
24 a surface of the wafer to provide temperature mapping of the

1 workpiece during processing. Platinum foil leads and copper leads are
2 utilized to electrically connect the temperature sensors. With the use
3 of numerous temperatures sensors across an entire workpiece surface,
4 numerous wires are required for coupling and monitoring. Such
5 numerous wired connections can break and/or adversely impact
6 processing of the workpiece or the temperature measurements taken of
7 the surface of the workpiece. Some temperature sensors require four
8 leads per sensor further impacting the processing and temperature
9 monitoring of the workpieces.

10 Therefore, there exists a need to provide improved temperature
11 monitoring of workpieces which overcomes the problems experienced in
12 the prior art.

13 14 SUMMARY OF THE INVENTION

15 The present invention includes electronic device workpieces,
16 methods of semiconductor processing and methods of sensing temperature
17 of an electronic device workpiece. Exemplary electronic device
18 workpieces include semiconductor wafers.

19 One electronic device workpiece includes a substrate having an
20 upper surface and a temperature sensing device borne by the substrate.
21 The temperature sensing device can comprise a preexisting device.
22 Alternatively, the temperature sensing device can be formed upon a
23 surface of the electronic device workpiece. The temperature sensing
24 device comprises a resistance temperature device (RTD) in one

embodiment. A plurality of temperature sensing devices are provided in temperature sensing relation with the electronic device workpiece in an exemplary embodiment.

An electrical interconnect is preferably provided upon the surface of the substrate. The electrical interconnect comprises a conductive trace in a preferred embodiment. The electrical interconnect is electrically coupled with the temperature sensing device. The electrical interconnect can be wire bonded to or physically coupled with the temperature sensing device. The electrical interconnect can be configured to couple the temperature sensing device with an edge of the electronic device workpiece. An interface can be provided to couple the electrical interconnects with external circuitry. Exemplary electrical circuitry includes a data gathering device, such as a digital computer.

An isolator is formed intermediate the temperature sensing device and electrical interconnect, and the substrate of the electronic device workpiece in one embodiment. The isolator provides electrical isolation. An exemplary isolator comprises silicon dioxide.

Temperature sensing devices are provided within a cavity formed within the substrate of the electronic device workpieces according to another embodiment. The cavity is preferably formed by an anisotropic etch forming sidewalls at an approximate angle of fifty-four degrees with respect to the surface of the substrate. Alternatively, temperature sensing devices are formed or positioned upon a surface of the electronic device workpiece.

1 The electronic device workpiece comprises a calibration workpiece
2 in one embodiment. In another embodiment, the electronic device
3 workpiece comprises a workpiece which undergoes processing from which
4 subsequent devices are formed, such as a silicon wafer.

5 6 BRIEF DESCRIPTION OF THE DRAWINGS

7 Preferred embodiments of the invention are described below with
8 reference to the following accompanying drawings.

9 Fig. 1 is an isometric view of an electronic device workpiece
10 having a plurality of temperature sensing devices.

11 Fig. 1A is an isometric view of an alternative electronic device
12 workpiece.

13 Fig. 1B is a cross-sectional view of one configuration of an
14 interface of the electronic device workpiece.

15 Fig. 2 is a cross-sectional view of a first embodiment of a
16 temperature sensing device upon the electronic device workpiece.

17 Fig. 2A is a cross-sectional view of an alternative configuration of
18 an electrical connection coupled with the temperature sensing device
19 shown in Fig. 2.

20 Fig. 3 is a cross-sectional view of a second embodiment of a
21 temperature sensing device upon the electronic device workpiece.

22 Fig. 4 is an elevated plan view of the temperature sensing device
23 shown in Fig. 3.

1 Fig. 5 is a cross-sectional view of a temperature sensing device
2 provided upon an upper surface of the electronic device workpiece.

3 Fig. 6 is a cross-sectional view illustrating an electrical connection
4 coupled with a temperature sensing device upon the electronic device
5 workpiece.

6 - DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

8 This disclosure of the invention is submitted in furtherance of the
9 constitutional purposes of the U.S. Patent Laws "to promote the
10 progress of science and useful arts" (Article 1, Section 8).

11 Referring to Fig. 1, an electronic workpiece 10 is illustrated.
12 Exemplary electronic device workpieces include a semiconductor wafer
13 or a crystal mask substrate. In one embodiment, electronic device
14 workpiece 10 includes a substrate 11 comprising a semiconductive
15 substrate. Substrate 11 can comprise silicon, silicon carbide and gallium
16 nitride. Alternatively, electronic device workpiece 10 can comprise other
17 substrates. In particular, electronic device workpiece 10 can comprise
18 other components configured for application within an electronic or
19 electrical device or configured for processing to form such components.

20 Electronic device workpiece 10 is coupled with external
21 circuitry 12. The illustrated external circuitry 12 includes plural
22 connections 14 and a resistance thermometer 16. An interface 18 is
23 provided in a preferred embodiment to provide convenient coupling of
24

1 circuitry formed upon electronic device workpiece 10 and electrical
2 connections 14 of circuitry 12.

3 External circuitry 12 can be implemented in other configurations.
4 For example, resistance thermometer 16 comprises a data gathering
5 device in alternative embodiments. Connections 14 are configured to
6 couple electronic device workpiece 10 with a digital computer configured
7 to monitor process conditions including the temperature of electronic
8 device workpiece 10. External circuitry 12 includes communication
9 devices in other embodiments of the invention to transmit process
10 conditions.

11 Electronic device workpiece 10 includes an upper surface 20 and
12 lower surface 22 opposite upper surface 20. Electronic device
13 workpiece 10 additionally includes an edge 24 which is circular in the
14 described embodiment.

15 According to the present invention, at least one temperature
16 sensing device 30 is provided upon at least one surface of electronic
17 device workpiece 10. A plurality of temperature sensing devices 30 are
18 provided upon electronic device workpiece 10 in a preferred
19 embodiment. In the illustrated embodiment, a plurality of temperature
20 sensing devices 30 are provided upon or supported by upper surface 20
21 of electronic device workpiece 10. Temperature sensing devices 30 are
22 preferably borne by substrate 11 of electronic device workpiece 10 and
23 may be formed upon lower surface 22 as well as upper surface 20.
24

1 In one embodiment, temperature sensing devices 30 comprise
2 resistance temperature devices (RTD). Resistance temperature devices
3 provide contact temperature sensing in preferred modes of operation.
4 In particular, resistance temperature devices can comprise a wire wound
5 device that provides a linear resistance change for a corresponding
6 temperature change. Typically, the coefficient of temperature of
7 resistance temperature devices is positive wherein the resistance through
8 the resistance temperature device increases as temperature increases.

9 Exemplary resistance temperature devices comprise sensitive
10 materials which provide a plurality of resistances corresponding to a
11 temperature profile. Resistance temperature devices can comprise
12 platinum, polysilicon or other sensitive materials.

13 In another embodiment, temperature sensing devices 30 comprise
14 diodes which provide a change in threshold voltage responsive to
15 temperature changes. Such voltage changes are sufficient to enable
16 monitoring of associated temperatures and extraction of temperature
17 information. Other temperature sensing devices 30 comprise
18 thermocouples which comprise two overlapping dissimilar metals to create
19 a voltage producing junction which varies dependent upon temperature
20 exposure. Further temperature sensing devices 30 include a thermistor
21 which comprises a mixture of metal oxides and encapsulated in an
22 isolator such as epoxy or glass.

23 As described in detail below, temperature sensing devices 30 can
24 be fabricated or formed upon the electronic device workpiece 10 or

1 comprise preexisting devices which are positioned and adhered upon or
2 attached to the electronic device workpiece 10. Fabricated temperature
3 sensing devices 30 are available from Watlow Electrical Manufacturing
4 Company of St. Louis, Missouri.

5 Electrical interconnects 40, 41 are provided to electrically couple
6 with individual temperature sensing devices 30. In a preferred
7 embodiment, electrical interconnects 40, 41 are formed upon upper
8 surface 20 of substrate 11. In embodiments where plural temperature
9 sensing devices 30 are provided, individual electrical interconnects 40, 41
10 are individually coupled with respective temperature sensing devices 30.

11 Electrical interconnects 40, 41 are formed upon upper surface 20
12 of substrate 11 in one embodiment. Such formed electrical
13 interconnects 40 preferably comprise conductive traces. The conductive
14 traces can comprise aluminum or other conductive materials. The
15 conductive traces are formed by sputtering in one fabrication method.
16 Electrical interconnects 40, 41 can comprise other conductors in other
17 embodiments. Electrical interconnects 40, 41 electrically couple
18 individual temperature sensing devices 30 with edge 22 of electronic
19 device workpiece 10.

20 An isolator (not shown in Fig. 1) is provided intermediate upper
21 surface 20 and temperature sensing devices 30 and electrical
22 interconnects 40, 41. The isolator comprises silicon dioxide or other
23 suitable insulative material.
24

1 Interface connection 18 is provided in electrical connection with
2 electrical interconnects 40, 41. The depicted interface connection 18 is
3 located proximate to edge 22 of electronic device workpiece 10.
4 Interface connection 18 is configured to provide electrical coupling of
5 electrical interconnects 40, 41 and the respective temperature sensing
6 devices 30 with circuitry 12 external of electronic device workpiece 10.
7 Exemplary interface connection configurations include tab tape, adapter,
8 flip chip connections, wire bond connections, and conductive adhesives.
9 Interface connection 18 can include other configurations in accordance
10 with the present invention.

11 Referring to Fig. 1A, an alternative interface connection 18a is
12 illustrated. Connection 18a provides electrical coupling of temperature
13 sensing devices 30 with electrical circuitry 12. The depicted interface
14 connection 18a is defined by edge 24 of workpiece 10.

15 Referring to Fig. 1B, yet another interface connection 18b is
16 illustrated. The depicted interface connection 18b comprises respective
17 mating plug and receptacle components 13, 15. Plug component 13 is
18 coupled with wires 14 of external circuitry 12 (although three wires 14
19 are shown in Fig. 1B, additional wires of circuitry 12 can be coupled
20 with plug 13). Plug 13 is configured for removable coupling with
21 component 15.

22 Receptacle component 15 is configured to receive plug 13 and for
23 attachment to electrical interconnections 40, 41 (only one
24 interconnection 40 is shown in Fig. 1B). When mated,

1 components 13, 15 couple external circuitry 12 with respective
2 interconnections 40, 41.

3 A plurality of interconnects 7 are used in the depicted
4 embodiment to couple internal electrical connections 17 of components
5 13, 15 with interconnections 40, 41. Exemplary interconnects 7 include
6 solder, solder balls, conductive epoxy, etc.

7 Referring to Fig. 2, electronic device workpiece 10 includes a
8 cavity 50 formed within substrate 11. Cavity 50 includes plural sloping
9 sidewalls 52, 53 and a bottom wall 54. Surface 20 of substrate 11
10 includes sidewalls 52, 53, and bottom wall 54. An exemplary cavity 50
11 has a depth of approximately 200 microns and bottom wall 54 has a
12 width of approximately 300 microns.

13 Cavity 50 is preferably formed by an anisotropic etch. An
14 exemplary anisotropic etch includes potassium hydroxide (KOH).
15 Utilization of an anisotropic etch provides sloping sidewalls 52, 53 within
16 cavity 50. Provision of sloping sidewalls 52, 53 facilitates fabrication of
17 conductors 40, 41 over surface 20 and isolator 56, and sidewalls 52, 53
18 of cavity 50. Sidewalls 52, 53 are preferably sloped at an angle within
19 the approximate range of 50 to 60 degrees with respect to upper
20 surface 20 of substrate 11. The most preferred embodiment provides
21 sidewalls 52, 53 having an angle of 54 degrees with respect to upper
22 surface 20.

23 Cavity 50 is formed by an isotropic etch in an alternative
24 embodiment. Wire bonded connections are preferably utilized in such

1 an embodiment to provide electrical coupling of interconnects 40, 41
2 upon surface 20 with the temperature sensing device 30 provided within
3 cavity 50.

4 One temperature sensing device 30 is shown borne by substrate 11
5 of electronic device workpiece 10. An isolation layer 56 is shown over
6 electronic device workpiece 10. Isolator 56 is formed over upper
7 surface 20 of substrate 11 including sidewalls 52, 53 and bottom wall 54
8 of cavity 50.

9 A preexisting temperature sensing device 30 is positioned and
10 adhered within cavity 50 in the depicted embodiment of Fig. 2.
11 Temperature sensing device 30 is adhered using standard thermal
12 conductive epoxies or adhesives in one embodiment. A temperature
13 sensing device is formed within cavity 50 in other embodiments
14 described below. Bottom wall 54 supports temperature sensing
15 device 30 in the depicted embodiment. Temperature sensing device 30
16 is supported by upper surface 20 of substrate 11 in other embodiments.

17 Electric interconnects or conductive traces 40, 41 are formed over
18 upper surface 20 and sidewall 52 in the depicted embodiment (only
19 conductive trace 40 is shown in Fig. 2). The illustrated electrical
20 interconnect 40 is provided over a portion of bottom wall 54. An
21 additional electrical connection 58 is utilized to electrically couple
22 temperature sensing device 30 with conductive trace or electrical
23 interconnect 40. In one embodiment, electrical connection 58 comprises
24 a wire connection, such as that formed by wire bonding. Other forms

1 of connections such as tab tape and flip chip connections can also be
2 employed. Connection 58 is preferably encapsulated to minimize damage
3 to connection 58. A dispensed epoxy 57 is utilized in one embodiment
4 to encapsulate connection 58. As shown, it is preferred to leave a
5 portion of the area adjacent temperature sensing device 30 free of
6 epoxy for accurate temperature sensing.

7 In other embodiments, contacting of conductive trace 40 with
8 temperature sensing device 30 is sufficient to electrically couple trace 40
9 and temperature sensing device 30.

10 Referring to Fig. 2A, the illustrated electrical interconnection 40
11 is formed outside of cavity 50. Connection 58 is used to couple
12 temperature sensing device 30 with the depicted interconnection 40 at
13 a location upon interconnection 40 outside of cavity 50.

14 Temperature sensing device 30 is preferably provided upon
15 electronic device workpiece 10 in a temperature sensing relation with
16 respect to electronic device workpiece 10. Temperature sensing
17 device 30 is configured to sense the temperature of an area of
18 electronic device workpiece 10 immediately adjacent the attached
19 device 30. In one embodiment, the resistance of temperature sensing
20 device 30 changes corresponding to changes in temperature. Such
21 changes in resistance change the voltage drop across temperature sensing
22 device 30 thereby changing signals (for example the currents of the
23 signals) passing through temperature sensing device 30. The generated
24 signals correspond to the temperature of the area of the electronic

1 device workpiece 10 being sensed. Electrical interconnects 40, 41
2 conduct the generated signals to interface connection 18 and external
3 circuitry 12 in the preferred embodiment. Exemplary external
4 circuitry 12 contains devices that convert the received signals to
5 localized temperatures at specific points.

6 Referring to Figs. 3 and 4, like reference numerals as used herein
7 refer to like components with any significant differences therebetween
8 represented by an alphabetical suffix such as "a". A temperature
9 sensing device 30a is shown formed within cavity 50 of substrate 11.
10 Electronic device workpiece 10 includes a conductive trace 40 extending
11 upon isolator 56 over a portion of upper surface 20, down sidewall 52
12 and across bottom wall 54 of cavity 50. Another conductive trace 41
13 is coupled with temperature sensing device 30a as shown in Fig. 4.

14 Temperature sensing device 30a is shown formed within cavity 50
15 upon conductor 40. The illustrated temperature sensing device 30a is
16 a resistance temperature device. The resistance temperature device
17 comprises a conductive material such as polysilicon or metals such as
18 platinum. Other materials can also be utilized. Similarly, a
19 combination of metals and polysilicon can also be utilized. In a
20 preferred embodiment, temperature sensing device 30a comprises
21 polysilicon deposited by chemical vapor deposition (CVD). The
22 deposited polysilicon can thereafter be doped by ion implantation or
23 diffusion to provide a desired resistivity. Alternatively, doped polysilicon
24 using PECVD techniques can also be deposited. The polysilicon

1 resistance temperature device can thereafter be patterned such as by
2 etching. Electrical interconnect 40 and temperature sensing devices 30
3 can be formed with thin film processing techniques or thick film
4 techniques using a stencil.

5 Referring to Fig. 4, the illustrated RTD temperature sensing
6 device 30a comprises polysilicon patterned in an exemplary serpentine
7 configuration. Temperature sensing device 30a can be configured in
8 other shapes and formats in other embodiments. Temperature sensing
9 device 30a is formed upon bottom wall 54 of cavity 50. Opposing ends
10 of temperature sensing device 30a are individually coupled with plural
11 electrical interconnects 40, 41. An electrical signal entering via one of
12 electrical interconnects 40, 41 passes through temperature sensing
13 device 30a and exits through the opposite electrical interconnect. A
14 change of temperature at bottom wall 54 results in a change in
15 resistance of temperature sensing device 30a. Accordingly, the voltage
16 drop across temperature sensing device 30a changes with respect to
17 fluctuations in temperature of the area of electronic device workpiece 10
18 adjacent device 30a. Electronic interconnects 40, 41 are configured to
19 conduct electrical signals which indicate a temperature of electronic
20 device workpiece 10.

21 Providing temperature sensing devices within cavities of the
22 electronic device workpiece enables temperature mapping of the
23 workpiece in three dimensions. Temperature sensing devices can be
24 provided both on the surfaces of an electronic device workpiece and

1 within cavities formed within the workpiece. Temperature sensing
2 devices upon one or both surfaces of the electronic device workpiece
3 enable temperature mapping in x-y directions upon the respective
4 surfaces of the workpiece. Providing temperature sensing devices within
5 cavities of the workpiece enable temperature sensing within the z
6 direction intermediate the surfaces of the workpiece.

7 Referring to Fig. 5, temperature sensing device 30a is formed over
8 surface 20 of substrate 11 of electronic device workpiece 10 and isolator
9 layer 56. In the depicted embodiment, at least a portion of
10 temperature sensing device 30a is formed or positioned upon electrical
11 interconnect 40. In the depicted embodiment, temperature sensing
12 device 30a is formed by chemical vapor deposition (CVD). In other
13 embodiments, temperature sensing device 30a is formed by alternative
14 processing methods. Isolator layer 56 is provided intermediate electrical
15 interconnect 40 and upper surface 20 of substrate 11.

16 Referring to Fig. 6, another construction for providing electrical
17 connection with temperature sensing device 30a is shown. Upper
18 surface 20 and lower surface 22 of substrate 11 are shown in Fig. 6.
19 Electrical interconnect 40 is formed upon upper surface 20 as previously
20 described.

21 The illustrated electronic device workpiece 10 also includes a via
22 44 formed within substrate 11. Via 44 enables electrical connection of
23 upper surface 20 with lower surface 22. In particular, another electrical
24 interconnection 42 is formed upon lower surface 22 of substrate 11.

1 Via 44 is also plugged with a conductive material forming electrical
2 interconnection 45 providing coupling of interconnections 40, 42. An
3 insulating layer 56a is preferably formed within via 44 to provide
4 insulation of interconnection 45.

5 Electrical interconnection 42 comprises a pad in the illustrated
6 configuration. Alternatively, electrical connection 42 can be formed to
7 extend to an edge of electronic device workpiece 10. Electrical
8 interconnection 42 can be coupled with external circuitry (not shown in
9 Fig. 6) enabling monitoring of temperatures of electronic device
10 workpiece 10.

11 In some embodiments, the described electronic device workpiece
12 is configured and utilized as a calibration wafer. Such calibration
13 wafers are typically placed within a workpiece processing chamber and
14 the chamber can be brought up to subject processing conditions at
15 typical elevated temperatures. Through the use of an electronic device
16 workpiece configured as a calibration wafer, the temperature at various
17 positions upon electronic device workpieces to be processed can be
18 determined. Thereafter, data provided by temperature sensing devices
19 located upon the electronic device workpiece can be utilized to provide
20 temperature control and modify some aspect of the processing chamber.

21 The processing chamber is preferably modified to provide a
22 uniform temperature distribution across the entire surface of the
23 electronic device workpiece being processed. In other processes, the
24

1 processing chamber is modified to provide varied temperatures across a
2 surface of the workpiece.

3 The modifications can be made with the calibration workpiece in
4 place within the processing chamber. The effect of such modifications
5 can be verified by the temperature sensing devices and associated
6 temperature monitoring equipment coupled with the devices. Thereafter,
7 the calibration workpiece is removed and the equipment having been
8 desirably calibrated can be utilized to process other electronic device
9 workpieces in mass.

10 In another embodiment, temperature sensing devices are provided
11 upon an electronic device workpiece which will actually be processed
12 and subsequently utilized to fabricate integrated circuitry or other
13 components. The temperature sensing devices can be fabricated upon
14 the electronic device workpiece during the fabrication of the electronic
15 device workpiece. In another embodiment, preexisting or prefabricated
16 temperature sensing devices are positioned and adhered upon the
17 electronic device workpiece.

18 In compliance with the statute, the invention has been described
19 in language more or less specific as to structural and methodical
20 features. It is to be understood, however, that the invention is not
21 limited to the specific features shown and described, since the means
22 herein disclosed comprise preferred forms of putting the invention into
23 effect. The invention is, therefore, claimed in any of its forms or
24

1 modifications within the proper scope of the appended claims
2 appropriately interpreted in accordance with the doctrine of equivalents.
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